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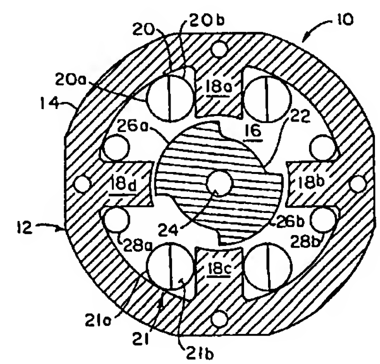
(54) **Auxiliary starting switched reluctance motor**

(57) A dynamo-electric machine such as a switched reluctance motor (10). A stator (14) has a central bore (16) and a plurality of inwardly salient poles (18A-18D) extending into the bore. A rotor (22) is mounted on a shaft (24) for rotation relative to the stator. The rotor has a plurality of outwardly salient poles (26A, 26B) extending into the bore. Stator windings (20, 21) are bifilar windings which produce an electro-magnetic field when a phase is energized. The bifilar windings return energy to the voltage source when the phase is de-energized. An auxiliary winding (28) is also installed on the stator. The auxiliary winding is energized, when the machine is off, to produce a magnetic field which causes rotation of the rotor to a preferred aligned position relative to the stator poles. This facilitates subsequent starting of the machine. An electrical circuit (30) energizes the auxiliary winding, when the machine is off; and then energizes the stator windings when the machine is started. The circuit de-energizes the auxiliary winding when the stator windings are energized. The auxiliary windings are also effective when used with motors having a stepped air gap (G) between the stator poles and rotor poles, or when the stator has a shifted pole configuration.

FIG. 2



EP 0 695 020 A2

Description

Background of the Invention

This invention relates to dynamo-electric machines and, more Particularly, to a switched reluctance motor (SRM) having an auxiliary starting capability.

In my United States patents 5,239,217, 5,122,697, 5,111,096, and 4,942,345, and in my co-pending patent applications 747,855/07, 043,294/08, 175,516/08, and 175,561/08, all of which are assigned to the same assignee as the present invention, I have described various improvements in switched reluctance motors. One problem in switched reluctance motors which still needs to be addressed is that of overcoming the inertia required to start the motor; i.e., producing enough starting torque to start the motor. The problem is particularly acute when the friction, or no load torque on the motor, is greater than torque that a magnet can produce to move the rotor to a preferred position for starting. One solution to the problem is to use a two-phase switched reluctance motor, for example, in place of a single phase SRM. However, such a solution has associated cost penalties because of the phase switching circuitry and associated sensors (rotor position sensors) which are required with the motor.

Summary of the Invention

Among the several objects of the present invention may be noted the prcvision of an improved dynamoelectric machine; the provision of such a dynamoelectric machine which is a single-phase switched reluctance motor; the provision of such a switched reluctance motor having at least one, and preferably two, auxiliary coils or windings to facilitate starting the motor; the provision of such a switched reluctance motor in which the coils are energized while the motor is off to align a rotor of the motor with the auxiliary coils; the provision of such a motor in which the auxiliary coils are switched out of a motor circuit after starting because the auxiliary coil is not required during normal motor running conditions; the provision of such a motor in which alignment of the rotor enables a phase winding of the motor to produce sufficient torque to start the motor; the provision of such a motor to employ a shifted pole to even out the available torque over the widest angle the auxiliary coils can produce to realign the rotor; the provision of such a motor having a stepped air gap between stator poles and rotor poles; the provision of such a motor in which the auxiliary coils require less copper than the phase winding; and, the provision of such a motor which is a less expensive motor than a two-phase motor because electronic switches and rotor sensors required with two-phase motors are not required.

In accordance with the invention, generally stated, a dynamo-electric machine such as a switched reluctance motor has a stator assembly and a rotor. The stator has a central bore and a plurality of inwardly salient poles extending into the bore. A rotor is mounted on a shaft for rotation relative to the stator. The rotor has a plurality of outwardly salient poles extending into the bore. Stator windings are installed on the stator; and, when energized, when the motor is running, produce an electro-magnetic field. An auxiliary winding is also installed on the stator. The auxiliary winding is energized, when the machine is off, to produce a magnetic field which causes rotation of the rotor to a preferred aligned position relative to the stator poles. This facilitates subsequent starting of the machine. An electrical circuit energizes the auxiliary winding, when the machine is off; and then energizes the stator windings when the machine is started. The circuit de-energizes the auxiliary winding when the stator windings are energized. The auxiliary winding is also installable on machines having stepped air gaps and shifted pole constructions. A method of machine operation to facilitate starting the motor is also disclosed. Other objects and features will be in part apparent and in part pointed out hereinafter.

Brief Description of the Drawings

Fig. 1 is a sectional view of a single-phase prior art switched reluctance motor;

Fig. 2 is a sectional view of single-phase switched reluctance motor of the present invention;

Fig. 3 is a view similar to Fig. 2, but with an auxiliary coil of the motor energized;

Fig. 4A is a schematic of an electrical control circuit used with the motor to start the motor;

Fig. 4B is an altemate embodiment of a control circuit for starting the motor;

Fig. 4C is another alternate embodiment of the control circuit;

Fig. 4D is a third alternate embodiment of the control circuit;

Fig. 5 illustrates an altemate auxiliary winding embodiment in which more copper is made available for the primary stator winding;

Fig. 6 is a sectional view of the motor of Figs. 2 and 3 with stepped rotor poles;

Fig. 7 is a sectional view of the motor with a shifted stator pole construction.

Fig. 8 is a sectional view of another embodiment of the motor; and,

Fig. 9 is a schematic of an alternate embodiment.

Corresponding reference characters indicate corresponding parts throughout the drawings.

Description of Preferred Embodiments

Referring to the drawings, a dynamo-electric machine 10 is shown in Fig. 1. Machine 10 is single-phase switched reluctance motor. As such, it first includes a stator assembly 12 including a stator 14 having a central bore 16. The stator further has a plurality of inwardly salient poles (18a-18d) extending into bore 16. While stator 14 is shown to have four poles, it will be understood that there could be more than four stator poles without departing from the scope of the invention. In addition, the stator assembly includes stator windings 20a, 20 and 21 installed on the stator poles. In Fig. 1, the windings are installed on opposed stator poles 18a, 18c. The stator windings are energized when the motor is running to produce a magnetic field, all as is well-known in the art. Coils 20 and 21 are each bifilar coils having respective coil sections 20a, 20b, and 21a, 21b. The bifilar coils return stored energy back to the DC bus when a phase is de-energized.

Next, a rotor 22 is mounted on a rotor shaft 24. The rotor is disposed in bore 16 for rotation relative to the stator assembly. When formed together, the rotor has a plurality of outwardly salient poles 26a, 26b. The poles extend outwardly into the bore. An air gap G is created between the respective outer ends of the stator and rotor poles. While rotor 22 is shown as only having two rotor poles; again, it could have more than two poles without departing from the scope of the invention. In Fig. 1, the rotor poles are shown to have a uniform outer surface so air gap G between the rotor and stator poles is uniform. As shown in Fig. 6, however, the rotor poles may have a stepped outer surface so there is a stepped air gap between the stator poles and rotor poles. Also as shown in Fig. 1, a magnet 27 may be attached to the outer end of the one of the stator poles. The function of magnet 27 is described in my previously mentioned patents and patent applications.

One problem with switched reluctance motors such as motor 10 is in starting the motor. When motor 10 is stopped, the position of the rotor poles relative to the stator poles is essentially random. This is the condition shown in Fig. 2. As a result, the starting torque necessary to be produced to next start the motor is variable over a wide range of values. The higher degree of torque necessary to overcome the inertia of the rotor, if the rotor has previously come to rest in an adverse position, can make starting the motor quite difficult.

To alleviate this problem, one, and preferably two auxiliary windings 28a and 28b are installed on stator assembly 12. Specifically, as shown in Fig. 2, winding 28a is installed on stator pole 18d, and winding 28b on stator pole 18b. These are opposed stator poles, and for the four pole construction of stator 14, the stator windings and auxiliary windings are installed on alternate poles. Importantly, and as described hereinafter, these auxiliary windings are energized when motor (10) is off, i.e. not running. By energizing the auxiliary windings at this time, a magnetic field is produced which causes rotor 22 to be rotated to a preferred aligned position relative to the stator poles. This is the condition shown in Fig. 3. As shown therein, energization of the auxiliary windings aligns the rotor poles with the stator poles about which the auxiliary windings are installed. Positioning the rotor as shown in Fig. 3, while the motor is otherwise "off", facilitates subsequent starting of the motor. With respect to windings 28a, 28b, it will be noted that they are smaller windings than windings 20 and 21. In the embodiments of Fig. 5, the stator poles 18b' and 18d' have an enlarged outer end so the stator poles are essentially T-shaped. This pole shape is advantageous in that it helps increase the amount of copper available for the primary stator windings 20, 21.

Referring to Figs. 4A-4D various embodiments of a control circuit means 30 are shown. Each embodiment 30a-30d of the control circuit means is for energizing the auxiliary winding or windings when motor 10 is "off", and for energizing the stator windings 20a, 20b when motor 10 is started. In each instance, circuit means 30 de-energizes the auxiliary windings 28a, 28b prior to, or when, the stator windings are energized.

In Figs. 4A-4D, stator windings 20 and 21 are shown connected in parallel. Auxiliary windings 28a, 28b are connected in series. A semi-conductor switch Q1 is connected in series with stator windings 20 and 21, and a diode D1 is series connected with the other stator winding. In each instance, a capacitor C1 is connected between an AC power source and the respective stator winding and auxiliary winding circuits. In Fig. 4A, a pair of switches 32, 34 are interposed between the power source and the respective winding circuits. Switch 32 is a normally open switch which, when closed, routes DC power from the power source, through a common point 36 with switch 34, through switch 32, to the auxiliary windings. This energizes the windings to produce rotation of rotor 22 to the preferred aligned position of Fig. 3. Switch 32 is then opened, de-energizing these windings. Next, switch 34 is closed to route current through the stator windings to run the motor. Switch 34 is closed during the entire time the motor is running; the switch being opened when the motor is stopped.

Referring to Fig. 4B, control circuit 30b includes a switch 38 which is a multi-position switch. Switch 38 is, for example, a three position switch having a first and motor "off" position in which neither the stator windings nor auxiliary windings are energized. The switch has a second and motor "start" position in which the auxiliary windings 28a, 28b, but not the stator windings 20 and 21, are energized. Finally, the switch has a third and motor "run" position in which auxiliary windings are de-energized, and the stator windings are energized. The user of the motor, to start the motor, turns the switch from its "off" to its "start" position. This effects alignment of rotor

22 as previously discussed. When the user then turns the switch to "run", the motor should readily start and run for so long as the user intends.

In Fig. 4C, control circuit 30c has a multi-position switch 40 which is similar to switch 38. Now, control circuit 30c further includes a timing means 42 which sequentially steps switch 40 from its "off" through its "start", to its "run" position in a timed sequence. Accordingly, the user need only activate the timing means for the timing means to automatically energize the auxiliary windings for a period sufficient for the rotor to be properly be aligned for starting, and then automatically de-energize the auxiliary windings, and energize the stator windings.

In Fig. 4D, a switch 44 is again similar to switch 38. Now, control circuit 30d further includes a sensing means 46 which sequentially steps switch 44 from its "off" through its "start", to its "run" position. Whereas timing means 42 automatically stepped switch 40 in a timed sequence, sensing means 46 steps the swich from its "start" to its "run" position, as a function of the sensed rotor position. Thus, the user first moves switch 44 from "off" to "start", energizing the auxiliary windings. When the rotor is moved to its Fig. 3 position, as previously described, sensing means 46 detects that the rotor has attained this position. The sensing means output indicating the rotor is now at its preferred aligned position automatically sequences the switch from its "start" to its "run" position, again to effect energization of the stator windings as previously described. Sensing means 46 may be any of a number of rotor position sensors such as a Hall effect sensor without departing from the scope of the invention.

Referring to Fig. 6, an alternate embodiment of the dynamo-electric machine is indicated generally 100. Again, the machine is a single-phase switched reluctance motor. The motor has a stator assembly 112 including a stator 114. The stator has a central bore 116 and a plurality of inwardly salient poles (118a-118d) extending into bore 116. As with motor 10, although stator 114 is shown to have four poles, it may have more than that number. The stator further includes stator windings 120, 121 installed on opposed stator poles 118a, 118c.

A rotor 122 is mounted on a rotor shaft 124. The rotor is disposed in bore 116 for rotation relative to the stator assembly and the includes respective poles 126a, 126b which have a stepped outer face so to form a stepped air gap with the corresponding stator poles. As before, while rotor 122 has only two rotor poles, it could have more than two poles. To aid in starting the motor, an auxiliary winding 128 is installed on stator pole 18d. Now, unlike the rotor pole construction of Figs. 2 and 3, the rotor poles 126a, 126b have a stepped outer face to create the stepped air gaps between the respective stator and rotor poles. Again, auxiliary windings are used for starting the motor as described hereinabove. A shifted pole switched reluctance motor is described in my co-pending patent application 747,855/07, filed August 20, 1991, which is incorporated herein by reference. One advantage of a shifted pole motor is that it also aids in starting the motor. Such a motor construction, used in accordance with the present invention is shown in Fig. 7. In Fig. 7, both of the stator poles on which auxiliary windings are installed are shifted with respect to the stator poles on which the main stator windings are installed. Again, switching between the auxiliary windings and main windings to effect efficient starting of the motor is as above described.

The motor configurations previously described represent 2:2 motors. In Fig. 8, a 4:4 motor 200 is shown. This motor has a stator assembly 212 including a stator 214 with stator teeth 218a-218h. A rotor 222 mounted on a rotor shaft 224 has salient rotor teeth 226a-226d. Motor 200 has main stator windings 220, 221, 223, and 225 and auxiliary windings 228a-228d. Operation of the motor is similar to that of the motors previously described. Motor 200 illustrates that the present invention is useful with motors whose stator pole/rotor pole ratio of 2(n):2(n) where n is a positive whole integer.

Fig. 9 illustrates a control circuit 30e similar to that in Fig. 4A, except for windings that are non-bifilar windings. Now, stator windings 20', 21' are series connected as are auxiliary windings 28a, 28b. A second semi-conductor switch Q2 is interposed between RUN switch 34 and the stator windings. A diode D2 is connected in parallel with switch Q2 and the series connected stator windings. Another diode D3 is connected across the stator windings and switch Q1. Operation of the control circuit 30e is such that windings 20', 21' do not now have to be bifilar windings in order to return energy to the DC bus.

What has been described is an improved dynamo-electric machine which is a single-phase switched reluctance motor. The motor has at least one, and preferably two, auxiliary coils to facilitate starting the motor. The auxiliary coils are energized while the motor is off to align a rotor of the motor with the auxiliary coils to help reduce the starting torque required to start the motor. The auxiliary coils are switched out of the motor circuit, after the motor is started since they are not required during normal operation of the motor. Alignment of the rotor enables a phase winding of the motor to produce sufficient torque to start the motor, this level of torque being less than would otherwise be required to start the motor. In addition, the motor can have stepped air gap and shifted pole construction. This evens out the available torque over the widest angle the auxiliary coils can produce, and helps realign the rotor. Because the auxiliary coils are not used to run the motor, they require less copper than the other phase windings of the motor. Consequently, the motor is less expensive motor than a two-phase motor having similar operating performance because electronic switches and rotor sensors required with a two-phase motor are not required.

In view of the foregoing, it will be seen that the several objects of the invention are achieved and other advantageous results are obtained.

As various changes could be made in the above constructions without departing from the scope of the inven-

tion, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

Claims

1. A dynamo-electric machine comprising:

   a stator assembly including a stator having a central bore and a plurality of inwardly salient poles extending into said bore;

   a rotor mounted on a shaft and installed in said central bore for rotation of said rotor relative to said stator, said rotor having a plurality of outwardly salient poles extending into said bore, there being an air gap between the respective outer ends of said stator and rotor poles;

   stator windings installed on the stator assembly, said stator windings being energized when said machine is running to produce a magnetic field; and,

   an auxiliary winding installed on said stator assembly, said auxiliary winding being energized when said machine is off to produce a magnetic field which causes rotation of said rotor to a preferred aligned position relative to said stator poles to facilitate subsequent starting of the machine.

2. The dynamo-electric machine of claim 1 further including control circuit means for energizing said auxiliary winding when said machine is off, and for energizing said stator windings when said machine is started, said circuit means de-energizing said auxiliary winding when said stator windings are energized.

3. The dynamo-electric machine of claim 2 further including a plurality of auxiliary windings, said auxiliary windings being installed on opposed stator poles.

4. The dynamo-electric machine of claim 3 wherein the stator windings and auxiliary windings are installed on altemate stator poles.

5. The dynamo-electric machine of claim 2 wherein at least one of the stator poles is a shifted pole and an auxiliary winding is installed on a stator pole opposed to the shifted pole.

6. The dynamo-electric machine of claim 2 wherein said control circuit means includes first switch means for energizing the auxiliary winding while the machine is off, and second switch means for subsequently energizing the stator windings.

7. The dynamo-electric machine of claim 2 wherein said control circuit means includes switch means including a multi-position switch having a first and machine "off" position in which neither the stator windings nor auxiliary windings are energized, a second and machine "start" position in which the auxiliary winding but not the stator windings are energized, and a third and machine "run" position in which auxiliary winding is de-energized, and the stator windings are energized.

8. The dynamo-electric machine of claim 8 further including timing means for sequentially stepping the switch means from its "off" to its "run" position in a timed sequence, the timing means energizing the auxiliary winding for a period sufficient for the rotor to properly be aligned for starting.

9. The dynamo-electric machine of claim 1 wherein the rotor poles have stepped outer faces to form a stepped air gap relative to the stator poles.

10. The dynamo-electric machine of claim 1 wherein said stator windings are bifilar windings.

11. A single-phase switched reluctance motor comprising:

    a stator having a central bore and a plurality of inwardly salient stator poles extending into the bore;

    a rotor mounted on a rotor shaft and installed in the central bore for rotation relative to the stator, the rotor having a plurality of outwardly salient poles extending into the bore;

    stator windings installed on the stator and being energized when said motor is running to produce a magnetic field;

    an auxiliary winding installed on the stator and being energized when the motor is not running to produce a magnetic field which causes rotation of the rotor to a preferred orientation aligned relative to the stator poles to facilitate subsequent starting of the motor; and,

    control means for energizing the auxiliary winding when the motor is not running, and for energizing the stator windings when the motor is started, the control means de-energizing the auxiliary winding when the stator windings are energized whereby use of the auxiliary winding to align the rotor reduces the torque necessary to start the motor.

12. The switched reluctance motor of claim 11 further including a plurality of auxiliary windings installed on opposed stator poles.

13. The switched reluctance motor of claim claim 11 wherein one of the stator poles is a shifted pole and the auxiliary winding is installed on a stator pole opposed to the shifted pole.

14. The switched reluctance motor of claim 13 wherein

said control means includes first switch means for energizing the auxiliary winding while the motor is off, and second switch for subsequently energizing the stator windings.

15. The dynamo-electric machine of claim 11 wherein said control means includes switch means including a multi-position switch having a first and motor "off" position in which neither the stator windings nor auxiliary winding is energized, a second and motor "start" position in which the auxiliary winding but not the stator windings is energized, and a third and motor "run" position in which auxiliary winding is de-energized, and the stator windings are energized..

16. The switched reluctance motor of claim 11 further including timing means for sequentially stepping the switch means from its "off" to its "run" position in a timed sequence, the timing means energizing the auxiliary winding for a period sufficient for the rotor to properly be aligned for starting.

17. The switched reluctance motor of claim 11 further including sensing means for sensing the rotor's position thereby to sense when the rotor is in an aligned position.

18. The switched reluctance motor of claim 11 further including a stepped air gap formed between the rotor and the stator.

19. The switched reluctance motor of claim 18 wherein the outer face of the rotor poles are stepped face thereby to form the stepped air gap.

20. The switched reluctance motor of claim 18 wherein the stator windings are bifilar windings.

21. In a switched reluctance motor having a stator with a central bore, a plurality of inwardly salient stator poles extending into the bore, and stator windings installed on the stator and energized when said motor is running to produce a magnetic field, and a rotor mounted on a rotor shaft and installed in the central bore for rotation relative to the stator, the rotor having a plurality of outwardly salient poles extending into the bore, the improvement comprising:

an auxiliary winding installed on the stator and energized when the motor is not running to produce a magnetic field which causes rotation of the rotor to a preferred aligned position relative to the stator poles to facilitate subsequent starting of the motor; and,

circuit means for energizing the auxiliary winding when the motor is not running, and for energizing the stator windings when the motor is started, the control means de-energizing the auxiliary winding when the stator windings are energized thereby to facilitate motor starting by reducing the required starting torque.

22. The improvement of claim 21 wherein the stator windings are bifilar windings and further including a plurality of auxiliary windings which are installed on opposed stator poles.

23. The improvement of claim 22 wherein one of the stator poles is a shifted pole and the auxiliary winding is installed on a stator pole opposed to the shifted pole.

24. The improvement of claim 21 wherein said circuit means includes switch means including a multi-position switch having a motor "off" position in which neither the stator windings nor auxiliary winding is energized, a motor "start" position in which the auxiliary winding but not the stator windings is energized, and a motor "run" position in which auxiliary winding is de-energized, and the stator windings are energized.

25. The switched reluctance motor of claim 24 further including timing means for sequentially stepping the switch means from its "off" to its "run" position in a timed sequence, the timing means energizing the auxiliary winding for a period sufficient for the rotor to properly be aligned for starting.

26. The switched reluctance motor of claim 25 further including sensing means for sensing the rotor's position thereby to sense when the rotor is in an aligned position.

27. The switched reluctance motor of claim 26 wherein the outer face of each rotor pole is stepped thereby to form a stepped air gap between the rotor and stator.

28. A method for starting a dynamo-electric machine, the machine having a stator with a central bore, a plurality of inwardly salient poles extending into said bore, and bifilar stator windings installed on the stator assembly, said stator windings being energized when said machine is running to produce a magnetic field, a rotor mounted on a rotor shaft and installed in said central bore for rotation of said rotor relative to said stator, said rotor having a plurality of outwardly salient poles extending into said bore, the method comprising:

causing rotation of said rotor to a preferred aligned position relative to said stator poles while the motor is not running; and,

subsequently energizing the stator windings to start the machine, rotating the rotor to the preferred

aligned position reducing the amount of starting torque required to start the machine.

29. The method of claim 28 wherein causing rotation of the rotor to a preferred aligned position uncludes:
installing an auxiliary winding on a stator pole;
energizing said auxiliary winding when said machine is off to create a magnetic field, the magnetic field causing rotation of the rotor; and,
de-energizing the auxiliary winding prior to energizing the stator windings.

30. The method of claim 29 further including a plurality of auxiliary windings on the stator poles, said auxiliary windings being installed on opposed stator poles.

31. The method of claim 29 further shifting one of stator poles and installing the auxiliary winding a stator pole opposed to the shifted pole.

32. The method of claim 29 further sensing the rotor's position to sense when the rotor is in an aligned position, and de-energizing the auxiliary winding when the alignment is sensed.

33. A method for starting a dynamo-electric machine having a stator with a central bore, a plurality of inwardly salient poles extending into said bore, stator windings installed on the stator assembly and energized when said machine is running to produce a magnetic field, and a rotor mounted on a rotor shaft and installed in said central bore for rotation of said rotor relative to said stator, said rotor having a plurality of outwardly salient poles extending into said bore, the method comprising:
installing an auxiliary winding on a stator pole;
causing rotation of said rotor to a preferred aligned position relative to said stator poles while the motor is notrunning by energizing said auxiliary winding when said machine is off to create a magnetic field, the magnetic field causing rotation of the rotor;
sensing the rotor's position to sense when the rotor is in an aligned position, and de-energizing the auxiliary winding when the alignment is sensed; and,
subsequently energizing the stator windings to start the machine, rotating the rotor to the preferred aligned position reducing the amount of starting torque required to start the machine.

34. The method of claim 33 further including a plurality of auxiliary windings on the stator poles, said auxiliary windings being installed on opposed stator poles.

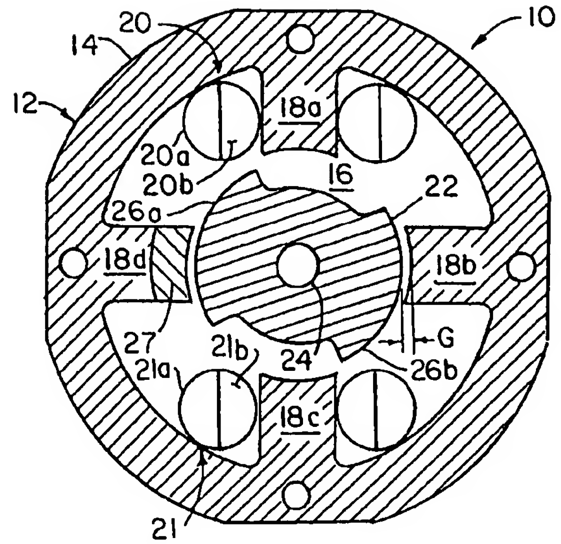


FIG. 1
PRIOR ART

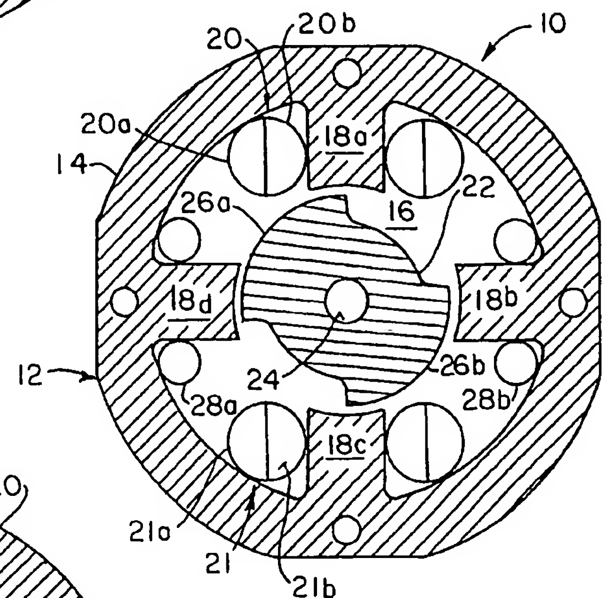


FIG. 2

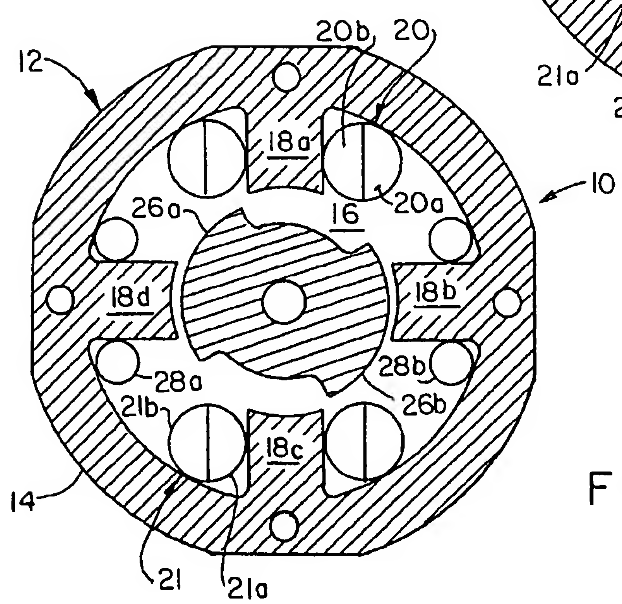


FIG. 3

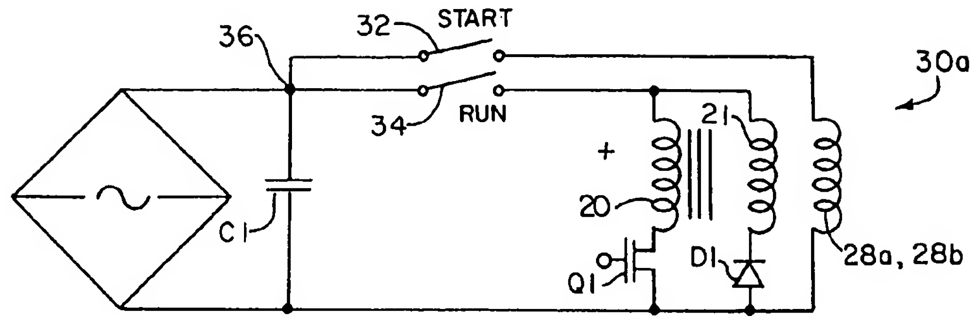


FIG. 4A

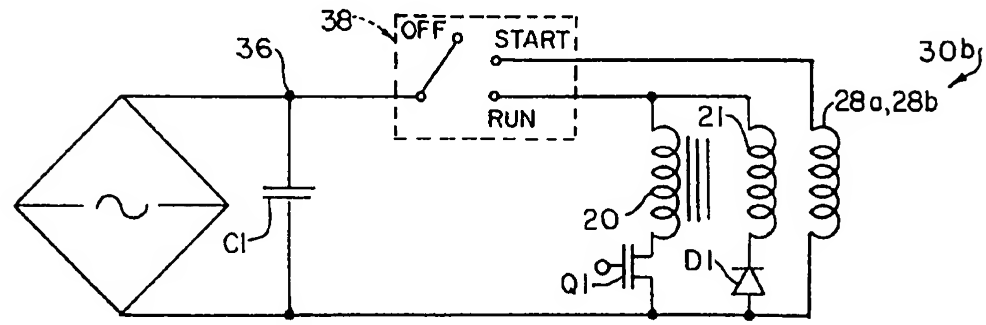


FIG. 4B

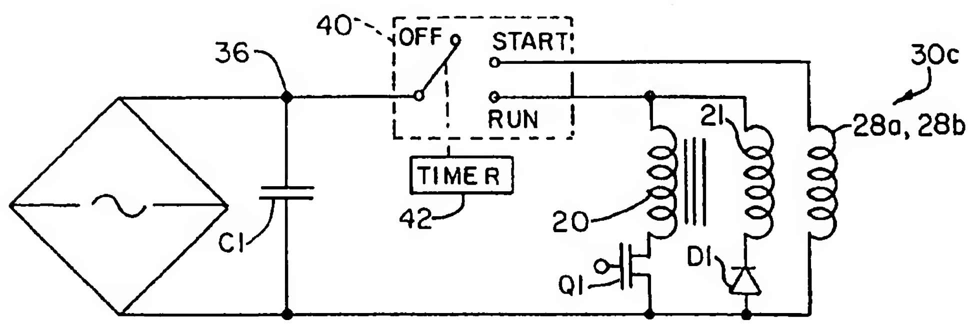


FIG. 4C

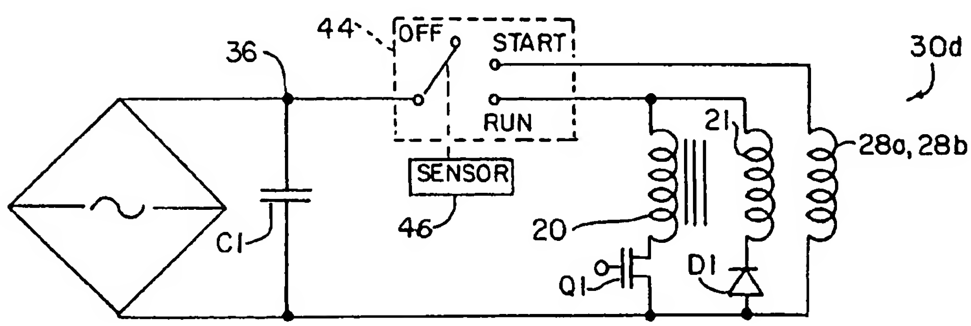


FIG. 4D

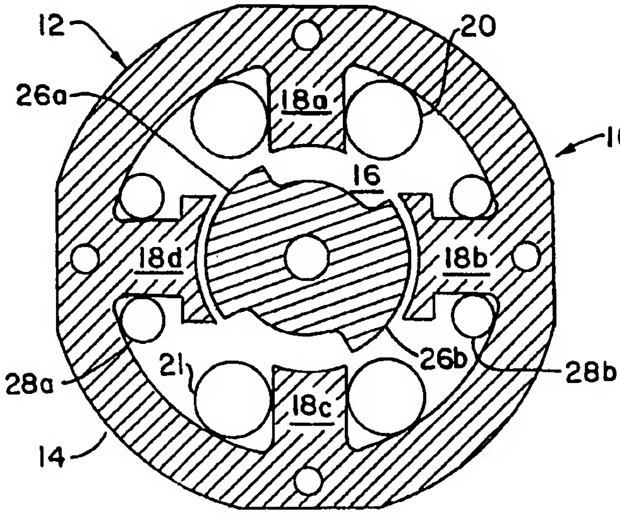


FIG. 5

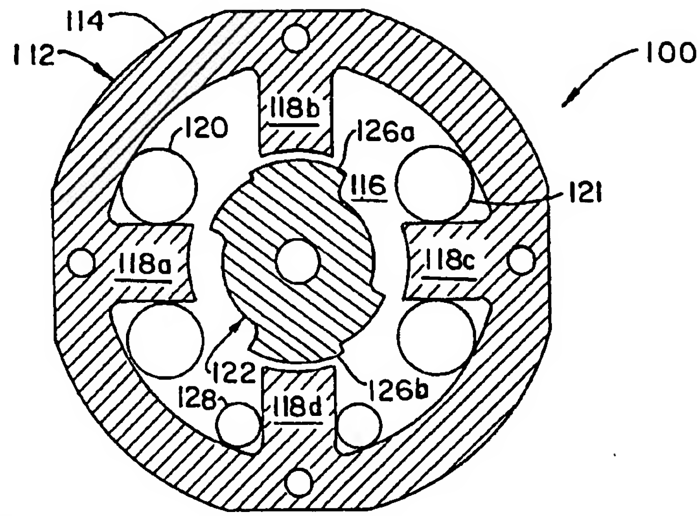


FIG. 6

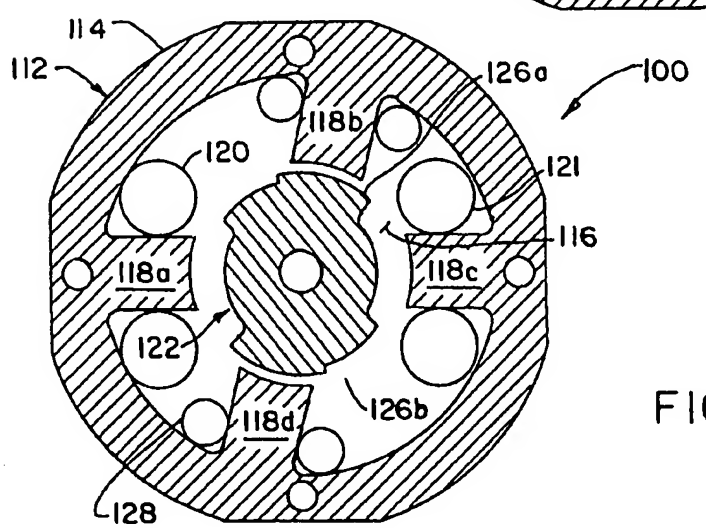
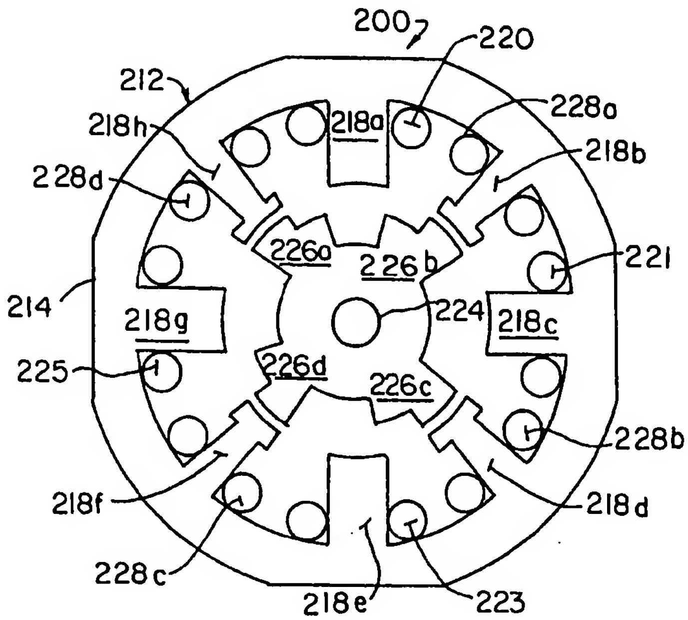


FIG. 7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228b
218f
218d
228c
218e
223

FIG.8

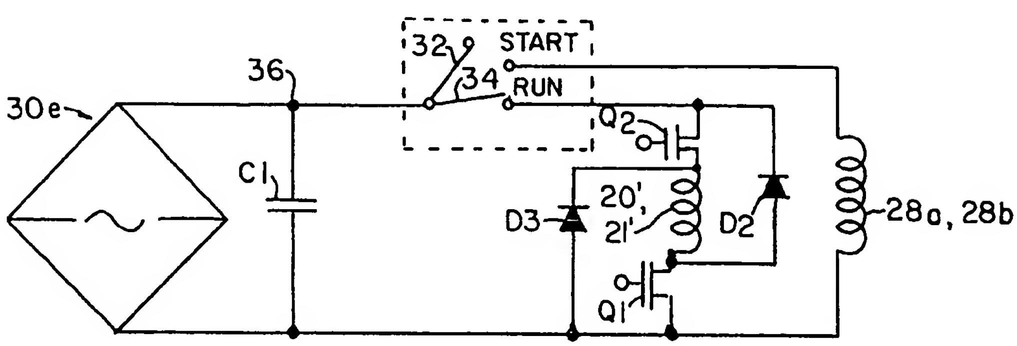
32
START
36
34
RUN
30e
Q2
C1
20',
21'
D3
D2
28a, 28b
Q1

FIG.9